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(54) Abstract Title
A LOWER LIMB PROSTHESIS

(57) A lower limb prosthesis for an above-knee amputee which includes an hydraulic piston and cylinder assembly (18) for resisting flexion of a knee joint (10) of the prosthesis during the stance phase, further includes a stumble sensing member (14F) associated with the knee joint and arranged to execute a flexion resistance actuation movement in response to a predetermined load on the prosthesis associated with a stumble condition. A motion transfer link member (30) couples the sensing member (14F) to a valve (18Q) of the piston and cylinder assembly (18), the arrangement of the sensing member (14F), the link member (30) and the valve (18Q) being such that the resistance of the assembly to knee flexion is increased so as to approach or attain a state in which the knee is locked against at least flexion when a stumble condition occurs.

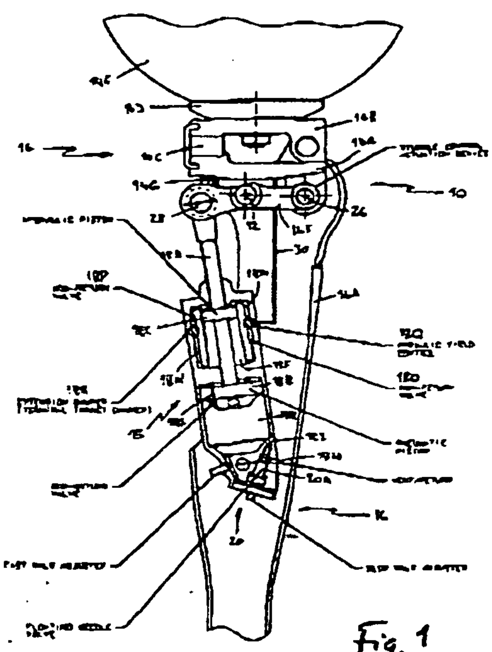

Fig. 1

HYDRO-PNEUMATIC SWING/STANCE CONTROL

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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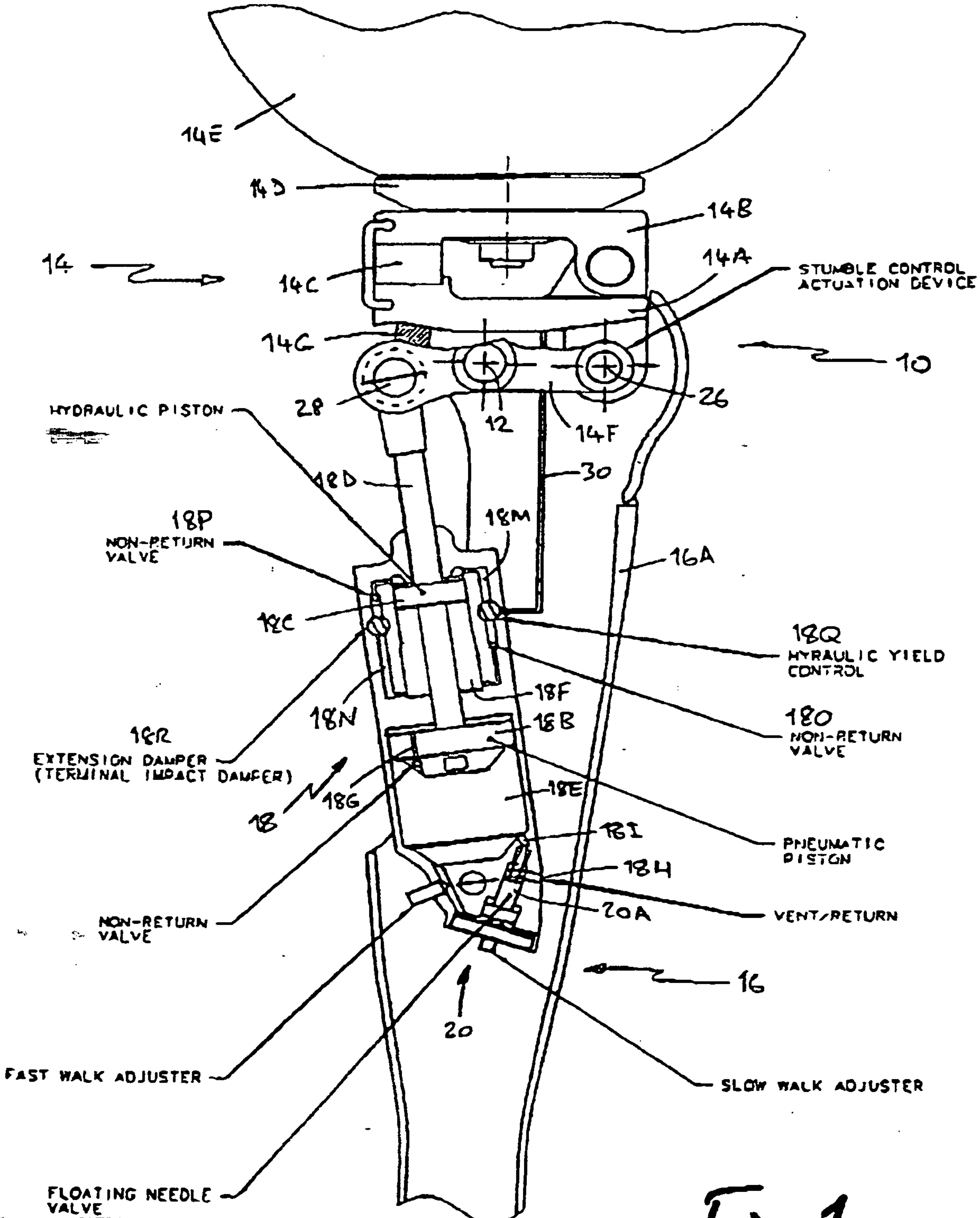
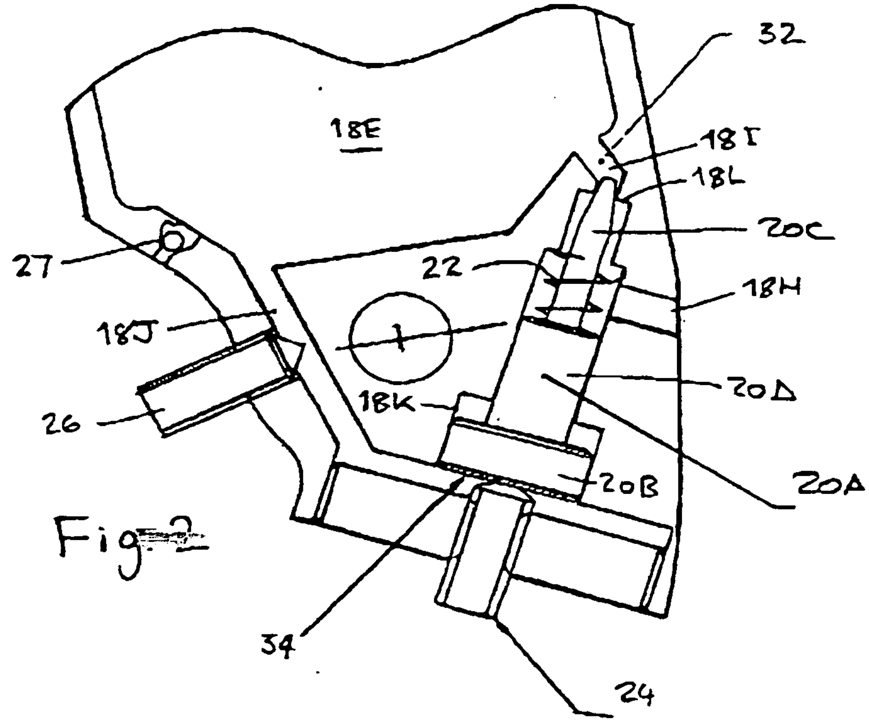


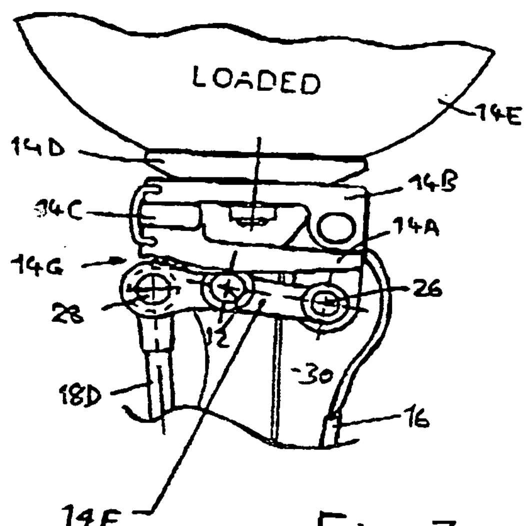
Fig. 1

HYDRO-PNEUMATIC SWING/STANCE CONTROL



32
18E
18I
18L
20C
27
22
18H
18J
20D
18K
26
20B
20A
34
24

Fig. 2



LOADED
14E
14D
14B
14C
14A
14G
26
28
12
30
18D
16
14F

Fig. 3

A LOWER LIMB PROSTHESIS

This invention relates to a lower limb prosthesis for an above-knee amputee, including an hydraulic piston and cylinder assembly for resisting knee joint flexion during the stance phase.

Our co-pending British Patent Application No. 9717380.1 discloses such a prosthesis. Knee flexion and extension, specifically rotation of the shin part of the prosthesis relative to a thigh part, is restricted by a piston and cylinder assembly having a piston rod connected to a knee chassis forming a portion of the thigh part and a cylinder pivotally connected to the shin part distally of the knee axis of rotation. For optimal control of both swing and stance phases, the assembly comprises two pistons mounted in tandem on a common piston rod, one being reciprocable within a first cylinder chamber containing hydraulic fluid, and another reciprocable within a second cylinder chamber containing a gas, in this case air. Both chambers have associated passages providing controlled communication of hydraulic fluid or air respectively, from one side of the respective piston to the other. In order that the hydraulic part of the assembly has predominant control during the stance phase while the pneumatic part has predominant control during the major part of the swing phase, the walls of the hydraulic chamber are profiled so that the piston it encloses is a close fit within the chamber only over an initial part of the flexion of the knee, typically from 0 to 30 degrees flexion.

In the above prior application, the flow of hydraulic fluid or air to or from each chamber is restricted by dynamically adjustable valves which are responsive to a electronic control system.

It is an object of the patent invention to provide a relatively simple means of controlling knee movements during swing and stance phases.

According to this invention, a lower limb prosthesis for an above-knee amputee includes an hydraulic piston and cylinder assembly for resisting flexion of a knee joint of the

prosthesis during the stance phase, wherein the prosthesis further includes a stumble sensing member associated with the knee joint and arranged to execute a flexion resistance actuating movement in response to a predetermined load on the prosthesis associated with a stumble condition, and a motion transfer link member coupling the sensing member to a valve of the piston and cylinder assembly, the arrangement of the sensing member, the link member and the valve being such that the resistance of the assembly to knee flexion is increased so as to approach or attain a state in which the knee is locked against at least flexion when a stumble condition occurs.

One way of detecting a stumble condition is to sense an excessive knee flexion moment. This may result, for instance, from the amputee catching the foot of the prosthesis just prior to a normal instant of heel contact, resulting in a abnormally high knee bending moment when the amputee's weight falls on the prosthesis. This is typically associated with the knee already being partly flexed, so that the hydraulic piston and cylinder assembly is already resiting flexion as part of a normal stance control function. For this reason the combination of the sensing member, link member, and valve is preferably responsive only to a knee-flexing moment above a predetermined threshold which is not normally reached during walking, descending stairs or descending an incline, the sensing member being mounted on and arranged so as to move in a load-sensing movement relative to the thigh part or the shin part of the prosthesis. The link member may be a cable, (e.g. a Bowden cable), a pushrod, a fluid connection, or other linkage connecting the sensing member to the valve.

Excessive knee flexion moments may be detected mechanically by making the sensing member in the form of a lever pivotally mounted on the thigh part or the shin part, with the respective pivot axis to the anterior of the knee axis of rotation, and forming the knee pivot on the lever so that the other of the two parts rotates relative to the lever as the knee flexes and extends. The lever is resiliently biased against the knee flexing moment, the degree of biasing being arranged such that it is only when the excessive knee flexing moment associated with a stumble condition that significant movement of the lever occurs.

In the preferred embodiment, the piston and cylinder assembly has a piston rod pivotally connected to a posterior end of the lever, posteriorly of the knee axis, and the cylinder part of the assembly is pivotally mounted on the shin part at an intermediate location between the knee axis and the foot of the prosthesis. The lever is pivotally mounted on the thigh part and movement of the lever relative to the thigh part due to a large knee flexing moment is transferred to the valve on the piston and cylinder assembly by the link member in the form of a Bowden cable or a pushrod system. In this way, during a stumble, the valve can be arrange to shut off a bypass passage between the upper and lower parts of the hydraulic chamber within the piston and cylinder assembly, thereby to lock the assembly and prevent further flexion. When the bending moment reduces to within a normal range (i.e. a range of magnitudes associated with normal walking on the level or on an incline), the hydraulic lock is removed and the knee regains its normal yielding function in the stance phase.

Another feature of the preferred embodiment is tandem hydraulic and pneumatic pistons and chambers, the hydraulic cylinder being profiled to resist movement at the knee only during the first 30 to 35 degrees of knee flexion from the extended state. Swing phase control is carried out largely by the pneumatic chamber, with variable swing phase resistance according to the speed of walking, as will be described below.

The invention will now be described with reference to the drawings in which:-

Figure 1 is a part cross-sectioned side view of a lower limb prosthesis in accordance with the invention;

Figure 2 is a detail of the lower end portion of the piston and cylinder assembly of the prosthesis shown in Figure 1, showing a dynamically variable pneumatic valve associated with a pneumatic chamber of the piston and cylinder assembly.

Figure 3 is a detail from Figure 1, showing the movement of a stumble sensing member during a stumble condition;

Referring to Figure 1, part of a lower limb prosthesis in accordance with the invention comprises a knee joint 10 with a knee pivot 12 defining a knee axis of rotation, connecting a thigh part 14 of the prosthesis to a shin part 16 of the prosthesis. The thigh part 14 comprises a knee chassis 14A, and anteriorly pivoted mounting plate 14B arranged to compress a posteriorly mounted elastomeric spring element 14C against the knee chassis when the prosthesis is loaded. The thigh part also has an alignment device 14D and a stump socket 14E.

The shin part 16 has a fibre-reinforced composite shin cradle 16A which houses a piston and cylinder assembly 18, acting as a flexion control device. The assembly 18 comprises a cylinder 18A which is pivotally coupled to the posterior part of the shin cradle 16A and two coaxial, longitudinally separated first and second pistons 18B, 18C having a common piston rod 18D which is pivotally coupled to the thigh part 14 as will be described hereinafter.

The piston and cylinder assembly 18 is a hybrid pneumatic and hydraulic device with the first piston 18B, hereinafter referred to as the "pneumatic piston", reciprocable in a first pneumatic piston chamber 18E, and the second piston 18C, hereinafter referred to as the "hydraulic piston", reciprocable in a second hydraulic chamber 18F. It will be noted that the pneumatic piston 18B contains a bypass passage 18G including a non-return valve which is oriented such that the pneumatic piston 18B resists movement of the piston rod 18D much more during flexion of the knee joint than during extension. Indeed, resistance to extension is almost negligible. The resistance due to the pneumatic part of the assembly 18 is controlled by a valve 20 having a dynamically variable orifice area and interrupting a passage 18I leading from that part of the chamber 18E the volume of which is reduced by piston movement during knee flexion.

In this embodiment, passage 18I vents the chambers 18E to the atmosphere at vent 18H in the lower part of the body of the assembly 18, the valve comprising a needle valve member 20A seated against a shoulder in the passage 18I.

The valve 20 is shown in more detail in Figure 2. Referring to Figure 2, it will be seen that the chamber 18E has a second port on the same side of the piston 18B as the port opening into passage 18I, this second port opening into a pressure sensing passage 18J formed in the body of the assembly 18. Valve member 20A floats in a bore extending between venting passage 18I and pressure sensing passage 18J. The bore is stepped so that a secondary sensing piston 20B formed as an enlarged head of the valve member 20A is reciprocable in the larger diameter portion 18K of the bore, the full area of this piston 20B being in communication with pressure sensing passage 18J. The needle portion 20C of the valve member 20A is biased away from engagement with the shoulder 18L in the venting passage 18I by means of a small spring 22 and the movement of the valve member 20A under the influence of spring 22 is limited by an adjustable stop in the form of a screw 24 arranged to abut the valve member at the end opposite the needle portion 20C. To control the air pressure applied to the secondary piston 20B, the pressure sensing passage contains a manually adjustable restrictor or valve in the form of a threaded value member 26 threaded in the piston and cylinder assembly body 18, member 26 having a profiled end portion shaped so as progressively to restrict passage 18J according to the degree of adjustment of the member 26.

A non-return valve 27 housed in the wall of the hydraulic chamber 18E prevents formation of a vacuum.

Valve 20 functions so as to increase the resistance to knee flexion as the speed of walking increases. The faster the amputee walks, the greater is the pressure developed by the pneumatic piston 18B within chamber 18E. It will be appreciated that the position adopted by the valve member 20A during flexion depends on the force resulting from the pressure applied to secondary piston 20B relative to the force due to pressure on the needle portion 20C, and relative to the biasing force applied on the valve member 20A by spring 22. Since secondary piston 20B has a much larger area than needle portion 20C and its supporting boss 20D, the increased pressure associated with increased walking speed, tends to reduce the orifice area between needle portion 20C and shoulder 18L of the passage 18I, thereby increasing the resistance to flexion. When the amputee is

walking slowly, the pressure developed in passage 18J and applied to the secondary piston 20B is relatively low, and the piston 20B rests against the adjuster stop 24.

In this way, the valve provides an advantageous variable pneumatic resistance to flexion during the swing phase of the walking cycle.

Referring again to Figure 1, the hydraulic part of the assembly 18A will now be briefly described. As in the above-mentioned co-pending British Patent Application, the hydraulic piston 18C is reciprocable within a chamber 18F having portions of different diameters. In the portion which houses the hydraulic piston 18C during the first 30 degrees of flexion, the diameter is such that the piston is a close fit within the chamber 18F. The other lower part of the chamber 18F is enlarged, to the extent that the piston 18C presents negligible resistance to movement when the angle of flexion is higher than 30 degrees or thereabouts. For this reason, and due to the higher intrinsic resistance which can be provided by an incompressible hydraulic fluid filling the chamber 18F, the hydraulic part of the piston and cylinder assembly 18 is the predominant controlling part when the angle of knee flexion is small (in this case less than 30 degrees). Above this angle of flexion, it is the pneumatic part of the assembly 18 which is the predominant controlling part.

It will be seen from Figure 1 that the hydraulic chamber 18F has two bypass passages 18M, 18N with respective oppositely oriented non-return valves 18O, 18P so that passage 18M provides communication between opposite sides of the hydraulic piston 18C during flexion, while passage 18N provides similar intercommunication during extension. The flow of fluid through each passage is restricted by respective adjustable valves 18Q, 18R, both of which are manually adjustable, that (18Q) in the first bypass passage 18M providing controlled yielding of the knee during the stance phase, and that (18R) in the second passage 18N providing terminal impact damping as the knee approaches full extension in the latter part of the stance phase.

An additional feature of the piston and cylinder assembly in this prosthesis is provision of means for substantially locking the knee against flexion using the yield valve 18Q or an additional valve member controlling the flow of fluid through the first passage 18M of the hydraulic part of the assembly 18. By actuating this flexion lock or substantial lock automatically in response to a high knee flexing moment, an automatic stumble control can be provided.

Actuation of the hydraulic flexion lock is achieved by rotatably mounting the shin part 16 on a lever 14F forming an extension of the thigh part 14 of the prosthesis. This lever extends in an anterior-posterior direction, being pivotally mounted on the knee chassis 14A which mounts a pivot shaft defining an anterior pivot axis 26 at approximately the same longitudinal position as the knee axis 12, but spaced to the anterior with respect to the knee axis. The knee axis 12, itself, is defined by a bearing housed in the lever 14F, providing a load-baring knee pivot. Extending posteriorly from knee axis 12, the lever 14F includes a third pivotal connection 28, in this case with the upper end of the piston rod 18D. A resilient buffer member 14G between the posterior end portion of the lever 14F and a posterior part of the knee chassis 14A restricts relative approaching movement of the lever 14F and the chassis 14A. Movement apart is limited by a restraining member (not shown).

It will be understood that a longitudinal load on the limb, providing such load is along a line running posteriorly of the knee axis 12, tends to cause movement of the lever 14F towards the chassis 14A. This movement is transmitted to the valve 18Q by means of a valve actuating link member 30 which takes the form of a Bowden cable having its inner wire and its outer sheath connected respectively to the chassis 14A and the lever 14F. At the other end of the cable 30 the wire and sheath are respectively connected to the valve member (not shown) of the hydraulic yield control valve 18Q (or a further stumble control valve in passage 18M), whereby the relative approaching movement of lever 14F and chassis 14A associated with a stumble causes movement of the valve member to close the passage 18M of the hydraulic part of the assembly 18. The hardness and dimensions of the buffer member 14G, which may be made of an elastomeric material such as

polyurethane, are selected such that during normal walking, the movement of lever 14F relative to the chassis 14A is negligible and provides no stumble controlling valve actuating effect. Since a stumble is invariably associated with an abnormally high knee flexing moment during the initial stages of knee joint flexion, such a moment can be detected by means of the level 14F to actuate the hydraulic lock.

In summary, the prosthesis provides both stance and swing phase control, in combination with stumble control, in a relatively simple mechanism. The pneumatic part of the piston and cylinder assembly 18 provides extension assistance during the swing phase, which is damped at terminal impact by the hydraulic part under independent control of valve 18R. Consequently, an extension assistance spring may be omitted which allows a wide range of yield resistance adjustment to be obtained, in combination with low activation effort on the part of the amputee compared with that required in use of a conventional hydraulic stance control device. In the case of a stumble or sudden knee flexion during the stance phase or when standing, the assembly 18 provides an hydraulic lock or a preset high stumble yield resistance, thereby preventing knee collapse.

KEY TO DRAWINGS

Figure 2 - PNEUMATIC VALVE CONTROL

18H : VENT TO ATMOSPHERE
Constant low pressure

20A : FLOATING VALVE
Pressure acting on differential areas at each end creates a force against the spring, varying the orifice size in proportion to the areas/pressures at each end of the valve.

22 : SPRING

24 : SLOW WALK ADJUSTER
Under low pressure conditions, adjusts open position of floating valve.

26 : FAST WALK RESTRICTOR VALVE
Controls the pressure acting upon the large pressure area. Adjusting this valve varies the force applied to close the floating valve at higher walking speeds.

32 : SMALL PRESSURE AREA

34 : LARGE PRESSURE AREA

Figure 3

14F : STUMBLE CONTROL LEVER

CLAIMS

1. A lower limb prosthesis for an above-knee amputee, including an hydraulic piston and cylinder assembly for resisting flexion of a knee joint of the prosthesis during the stance phase, wherein the prosthesis further includes a stumble sensing member associated with the knee joint and arranged to execute a flexion resistance actuating movement in response to a predetermined load on the prosthesis associated with a stumble condition, and a motion transfer link member coupling the sensing member to a valve of the piston and cylinder assembly, the arrangement of the sensing member, the link member and the valve being such that the resistance of the assembly to knee flexion is increased so as to approach or attain a state in which the knee is locked against at least flexion when a stumble condition occurs.

2. A prosthesis according to claim 1, wherein the combination of the sensing member, the link member and the valve is responsive only to a knee flexing moment above a predetermined threshold which is not normally reached during normal walking, descending stairs or descending an incline.

3. A prosthesis according to claim 1 or claim 2, wherein the sensing member is mounted on and arranged so as to move relative to a thigh part or a shin part of the prosthesis, the link member being a cable, a pushrod, fluid connection, or other linkage connecting the sensing member to the said valve.

4. A prosthesis according to claim 3, wherein the sensing member comprises a lever pivotally mounted on the thigh part or the shin part with a pivot axis to the anterior of the knee axis of rotation, and wherein the other of the said parts is pivotally mounted on the lever to define the knee axis, the lever being resiliently biased against the said actuating movement about the anterior pivot axis.